Chapter 5: Efficacy of Cooling Water Intake Structure Technologies

INTRODUCTION

To support the Section 316(b) new facility rulemaking, the Agency has compiled data on the performance of the range of technologies currently used to minimize impingement and entrainment (I&E) at power plants nationwide. The goal of this data collection and analysis effort has been to determine whether specific technologies can be demonstrated to provide a consistent level of proven performance. This information has been used throughout the rulemaking process including comparing specific regulatory options and their associated costs and benefits. It provides the supporting information for the selected alternatives, which require wet, closed-cycle cooling systems (under Track 1) with the option of demonstrating comparable performance (under Track II) using alternative technologies. Throughout this chapter, baseline technology performance refers to the performance of conventional, wide mesh traveling screens that are not intended to prevent I&E. Alternative technologies generally refer to those technologies, other than closed-cycle cooling systems that can be used to minimize I&E. Overall, the Agency has found that performance and applicability vary to some degree based on site-specific conditions. However, the Agency has also determined that alternative technologies can be used effectively on a widespread basis with proper design, operation, and maintenance.

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5.1 SCOPE OF DATA COLLECTION EFFORTS

Since 1992, the Agency has been evaluating regulatory alternatives under Section 316(b) of the Clean Water Act. As part of these efforts, the Agency has compiled readily available information on the nationwide performance of I&E reduction technologies. This information has been obtained through:

- Literature searches and associated collection of relevant documents on facility-specific performance.
- Contacts with governmental (e.g., TVA) and non-governmental entities (e.g., EPRI) that have undertaken national or regional data collection efforts/performance studies
- Meetings with and visits to the offices of EPA Regional and State agency staff as well as site visits to operating power plants.

It is important to recognize that the Agency did not undertake a systematic approach to data collection, i.e., the Agency did not obtain all of the facility performance data that are available nor did it obtain the same level of information for each facility. The Agency is not aware of such an evaluation ever being performed nationally. The most recent national data compilation was undertaken by the Electric Power Research Institute (EPRI) in 2000, see *Fish Protection at Cooling Water Intakes, Status Report*. The findings of this report are cited extensively in the following subsections. However, EPRI's analysis was primarily a literature collection and review effort and was not intended to be an exhaustive compilation and analysis of all data.

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5.2 DATA LIMITATIONS

Because the Agency did not undertake a systematic data collection effort with consistent data collection procedures, there is significant variability in the information available from different data sources. This leads to the following data limitations:

- Some facility data include all of the major species and associated life stages present at an individual facility. Other facilities only include data for selected species and/or life stages.
- Much of the data were collected in the 1970s and early 1980s when existing facilities were required to complete their initial 316(b) demonstrations.
- Some facility data includes only initial survival results, while other facilities have 48 to 96-hour survival data. These data are relevant because some technologies can exhibit significant latent mortality after initial survival.
- The Agency did not review data collection procedures, including quality assurance/quality control protocols.
- Some data come from laboratory and pilot-scale testing rather than full-scale evaluations.

The Agency recognizes that other than closed-cycle cooling and velocity reduction technologies the practicality or effectiveness of alternative technologies not be uniform under all conditions. The chemical and physical nature of the waterbody, the facility intake requirements, climatic conditions, and biology of the area all effect feasibility and performance. However, despite the above limitations, the Agency has concluded that significant general performance expectations can be implied for the range of technologies and that one or more technologies (or groups of technologies) can provide significant I&E protection at most sites. In addition, in the Agency's view many of the technologies have the potential for even greater applicability and higher performance when facilities are required to optimize their use.

The remainder of this chapter is organized by groups of technologies. A discussion of wet, closed-cycle cooling tower performance is included to present the Agency's view of the likely minimum standard that Track II facilities will be required to achieve (although each facility will have to present it's own closed-cycle system scenario). A brief description of conventional, once-through traveling screens is also provided for comparison purposes. Fact sheets describing each technology, available performance data, and design requirements and limitations are provided in Attachment A. It is important to note that this chapter does not provide descriptions of all potential CWIS technologies. (ASCE 1982 generally provides such an all-inclusive discussion). Instead, the Agency has focused on those technologies that have shown significant promise at the laboratory, pilot-scale, and/or full-scale levels in consistently minimizing impingement and/or entrainment. In addition, this chapter does not identify every facility where alternative technologies have been used but rather only those where some measure of performance in comparison to conventional screens has been made. The chapter concludes with a brief discussion of how the location of intakes (as well as the timing of water withdrawals) could also be used to limit potential I&E effects at new facilities.

Finally, under Track II in the new facility rule, facilities may use habitat restoration projects as an additional means to demonstrate consistency with Track I performance. Such projects have not had widespread application at existing facilities. Because the nature, feasibility, and likely effectiveness of such projects would be highly site-specific, the Agency has not attempted to quantify their expected performance level herein.

5.3 CLOSED-CYCLE WET COOLING SYSTEM PERFORMANCE

Under Track I, facilities are required meet requirements based on the design and installation of wet, closed-cycle cooling systems. Although flow reduction serves the purpose of reducing both impingement and entrainment, these requirements function as the primary entrainment reduction portion of Track I. Under Track II, new facilities must demonstrate I&E performance comparable to 90 percent of the performance of a wet, closed-cycle system designed for their facility. In part, to evaluate the feasibility of meeting this requirement and to allow comparison of costs/benefits of alternatives, the Agency determined the likely range in flow reductions between wet, closed-cycle cooling systems compared to once-through systems. In closed-cycle systems, certain chemicals will concentrate as they continue to be recirculated through the tower. Excess buildup of such chemicals, especially total dissolved solids, affects the tower performance. Therefore, some water (blowdown) must be discharged and make-up water added periodically to the system.

See Section 2.3.5 of Chapter 2 of this document for further discussion of flow reduction using wet, closed-cycle cooling.

An additional question that the Agency has considered is the feasibility of constructing salt-water make-up cooling towers. The Agency contacted Marley Cooling Tower (Marley), which is one of the largest cooling tower manufacturers in the world. Marley provided a list of facilities (Marley, 2001) that have installed cooling towers with marine or otherwise high total dissolved solids/brackish make-up water. It is important to recognize that this represents only a selected group of facilities constructed by Marley worldwide; there are also facilities constructed by other cooling tower manufacturers. For example, Florida Power and Light's (FPL) Crystal River Units 4 and 5 (about 1500 MW) use estuarine water make-up.

5.4 CONVENTIONAL TRAVELING SCREENS

For impingement control technologies, performance is compared to conventional traveling screens as a baseline technology. These screens are the most commonly used intakes at older existing facilities and their operational performance is well established. In general, these technologies are designed to prevent debris from entering the cooling water system, not to minimize I&E. The most common intake designs include front-end trash racks (usually consisting of fixed bars) to prevent large debris from entering system. They are equipped with screen panels mounted on an endless belt that rotates through the water vertically. Most conventional screens have 3/8-inch mesh that prevents smaller debris from clogging the condenser tubes. The screen wash is typically high pressure (80 to 120 pounds per square inch (psi)). Screens are rotated and washed intermittently and fish that are impinged often die because they are trapped on the stationary screens for extended periods. The high-pressure wash also frequently kills fish or they are re-impinged on the screens. Conventional traveling screens are used by approximately 60 percent of all existing steam electric generating units in the U.S. (EEI, 1993).

5.5 ALTERNATIVE TECHNOLOGIES

5.5.1 Modified Traveling Screens and Fish Handling and Return Systems

Technology Overview
Conventional traveling screens can be modified so that fish, which are impinged on the screens, can be removed with minimal stress and mortality. “Ristroph Screens” have water-filled lifting buckets which collect the impinged organisms and transport them to a fish return system. The buckets are designed such that they will hold approximately 2 inches of water once they have cleared the surface of the water during the normal rotation of the traveling screens. The fish bucket holds the fish in water until the screen rises to a point where the fish are spilled onto a bypass, trough, or other protected area (Mussalli, Taft, and Hoffman, 1978). Fish baskets are also a modification of a conventional traveling screen and may be used in conjunction with fish buckets. Fish baskets are separate framed screen panels that are attached to vertical traveling screens. An essential feature of modified traveling screens is continuous operation during periods where fish are being impinged. Conventional traveling screens typically operate on an intermittent basis. (EPRI, 2000 and 1989; Fritz, 1980). Removed fish are typically returned to the source water body by sluiceway or pipeline. ASCE 1982 provides guidance on the design and operation of fish return systems.

Technology Performance
Modified screens and fish handling and return systems have been used to minimize impingement mortality at a wide range of facilities nationwide. In recent years, some researchers, primarily *Fletcher 1996,* have evaluated the factors that effect the success of these systems and described how they can be optimized for specific applications. Fletcher cited the following as key design factors:

- Shaping fish buckets/baskets to minimize hydrodynamic turbulence within the bucket/basket
- Using smooth woven screen mesh to minimize fish descaling
- Using fish rails to keep fish from escaping the buckets/baskets
- Performing fish removal prior to high pressure wash for debris removal
- Optimizing the location of spray systems to provide gentler fish transfer to sloughs
- Ensuring proper sizing and design of return troughs, sluiceways, and pipes to minimize harm.

In 1993 and 1994, the Salem Generating Station specifically considered Fletcher’s work in the modification of their fish handling system. In 1996, the facility subsequently reported an increase in juvenile weakfish impingement survival from 58 percent to 79 percent with an overall weakfish reduction in impingement losses of 51 percent. 1997 and 1998 test data for Units 1 and 2 showed: white perch had 93 to 98 percent survival, bay anchovy had 20 to 72 percent survival, Atlantic croaker had 58 to 98 percent survival, spot had 93 percent survival, herring had 78 to 82 percent survival, and weakfish had 18 to 88 percent survival.

Additional performance results for modified screens and fish return systems include:

- 1988 studies at the Diablo Canyon and Moss Landing Power Plants in California found that overall impingement mortality could be reduced by as much as 75 percent with modified traveling screens and fish return sluiceways.

- Impingement data collected during the 1970s from Dominion Power’s Surry Station (Virginia) indicated a 93.8 percent survival rate of all fish impinged. Bay anchovies had the lowest survival 83 percent. The facility has modified Ristroph screens with low pressure wash and fish return systems.

- In 1986, the operator of the Indian Point Station (New York) redesigned fish troughs on the Unit 2 intake to enhance survival. Impingement injuries and mortality were reduced from 53 to 9 percent for striped bass, 64 to14 percent for white perch, 80 to 17 percent for Atlantic tomcod, and 47 to 7 percent for pumpkinseed.

- 1996 data for Brayton Point Units 1-3 showed 62 percent impingement survival for continuously rotated conventional traveling screens with a fish return system.

- In the 1970s, a fish pump and return system was added to the traveling screens at the Monroe Power Plant in Michigan. Initial studies showed 70 to 80 percent survival for adult and young-of-year gizzard shad and yellow perch.

- At the Hanford Generating Plant on the Columbia River, late 1970s studies of modified screens with a fish return system showed 79 to 95 percent latent survival of impinged Chinook salmon fry.

- The Kintigh Generating Station in New Jersey has modified traveling screens with low pressure sprays and a fish return system. After enhancements to the system in 1989, survivals of generally greater than 80 percent have been observed for rainbow smelt, rock bass, spottail shiner, white bass, white perch, and yellow perch. Gizzard shad survivals have been 54 to 65 percent and alewife survivals have been 15 to 44 percent.

- The Calvert Cliffs Station in Maryland has 12 traveling screens that are rotated for 10 minutes every hour or when pressure sensors show pressure differences. The screens were originally conventional and are now dual flow. A high pressure wash and return system leads back to the Chesapeake Bay. Twenty-one years of impingement monitoring show total fish survival of 73 percent.

- At the Arthur Kill Station in New York, 2 of 8 screens are modified Ristroph type; the remaining six screens are conventional type. The modified screens have fish collection troughs, low pressure spray washes, fish flap seals, and separate fish collection sluices. 24-hour survival for the unmodified screens averages 15 percent, while the two modified screens have 79 and 92 percent average survival rates, respectively.

In summary, performance data for modified screens and fish returns are somewhat variable due to site conditions and variations in unit design and operation. However, the above results generally show that at least 70-80 percent reductions in impingement can be achieved over conventional traveling screens.

5.5.2 Cylindrical Wedgewire Screens

Technology Overview
Wedgewire screens are designed to reduce entrainment by physical exclusion and by exploiting hydrodynamics. Physical exclusion occurs when the mesh size of the screen is smaller than the organisms susceptible to entrainment. The screen mesh ranges from 0.5 to 10 mm. Hydrodynamic exclusion results from maintenance of a low through-slot velocity, which, because of the screen's cylindrical configuration, is quickly dissipated, thereby allowing organisms to escape the flow field (Weisberd et al, 1984). Adequate countercurrent flow is needed to transport organisms away from the screens. The name of these screens arises from the triangular or "wedge" cross section of the wire that makes up the screen. The screen is composed of wedge-wire loops welded at the apex of their triangular cross section to supporting axial rods presenting the base of the cross section to the incoming flow (Pagano et al, 1977).

Wedgewire screens may also be referred to as profile screens or Johnson screens.

Technology Performance
Wide mesh wedgewire screens have been used at 2 Ahigh flow@ power plants: J.H. Campbell Unit 3 (770 MW) and Eddystone Units 1 and 2 (approximately 700 MW combined). At Campbell, Unit 3 withdraws 400 million gallons per day (mgd) of water from Lake Michigan approximately 1,000 feet from shore. Unit 3 impingement of gizzard shad, smelt, yellow perch, alewife, and shiner species is significantly lower than Units 1 and 2 that do not have wedgewire screens. Entrainment is not a major concern at the site because of the deep water, offshore location of the Unit 3 intake. Eddystone Units 1 and 2 withdraw over 500 mgd of water from the Delaware River. The cooling water intakes for these units were retrofitted with wedgewire screens because over 3 million fish were reportedly impinged over a 20-month period. The wedgewire screens have generally eliminated impingement at Eddystone. Both the Campbell and Eddystone wedgewire screens require periodic cleaning but have operated with minimal operational difficulties.

Other plants with lower intake flows have installed wedgewire screens but there are limited biological performance data for these facilities. The Logan Generating Station in New Jersey withdraws 19 MGD from the Delaware River through a 1-mm wedgewire screen. Entrainment data show 90 percent less entrainment of larvae and eggs then conventional screens. No impingement data are available. Unit 1 at the Cope Generating Station in South Carolina is a closed cycle unit that withdraws about 6 MGD through a 2-mm wedgewire screen, however, no biological data are available. Performance data are also unavailable for the Jeffrey Energy Center, which withdraws about 56 MGD through a 10-mm screen from the Kansas River in Kansas. The system at the Jeffrey Plant has specifically operated since 1982 with no operational difficulties. Finally, the American Electric Power Corporation has installed wedgewire screens at the Big Sandy (2 MGD) and Mountaineer (22 MGD) Power Plants, which withdraw water from the Big Sandy and Ohio Rivers, respectively. Again, no biological test data are available for these facilities.

Wedgewire screens have been considered/tested for several other large facilities. In situ testing of 1 and 2-mm wedgewire screens was performed in the St. John River for the Seminole Generating Station Units 1 and 2 in Florida in the late 1970s. This testing showed virtually no impingement and 99 and 62 percent reductions in larvae entrainment for the 1-mm and 2-mm screens, respectively, over conventional screen (9.5 mm) systems. The State of Maryland conducted testing in 1982 and 1983 of 1, 2, and 3-mm wedgewire screens at the Chalk Point Generating Station, which withdraws water from the Patuxent River in Maryland. The 1-mm wedgewire screens were found to reduce entrainment by 80 percent. No impingement data were available. Some biofouling and clogging was observed during the tests. In the late 1970s, Delmarva Power and Light conducted laboratory testing of fine mesh wedgewire screens for the proposed 1540 MW Summit Power Plant. This testing showed that entrainment of fish eggs (including striped bass) could effectively be prevented with slot widths of l mm or less, while impingement mortality was expected to be less than 5 percent. Actual field testing in the brackish water of the proposed intake canal required the screens to be removed and cleaned as often as once every three weeks.

As shown by the above data, it is clear that wedgewire screen technology has not been widely applied in the steam electric industry to date. It has only been installed at a handful of power plant facilities nationwide. However, the limited data for Eddystone and Campbell indicate that wide mesh screens, in particular, can be used to minimize impingement. Successful use of the wedgewire screens at Eddystone as well as Logan in the Delaware River (high debris flows) suggests that the screens can have widespread applicability. This is especially true for facilities that have relatively low intake flow requirements (i.e., closed-cycle systems). Yet, the lack of more representative full-scale plant data makes it impossible to conclusively say that wedgewire screens can be used in all environmental conditions. There are no full-scale data specifically for marine environments where biofouling and clogging are significant concerns. In addition, it is important to recognize that there must sufficient crosscurrent in the waterbody to carry organisms away from the screens.

Fine mesh wedgewire screens (0.5 - 1 mm) also have the *potential* for use to control both I&E. The Agency is not aware of any fine-mesh wedgewire screens that have been installed at power plants with high intake flows (>100 MGD). However, they have been used at some power plants with lower intake flow requirements (25-50 MGD) that would be comparable to a large power plant with a closed-cycle cooling system. With the exception of Logan, the Agency has not identified any full-scale performance data for these systems. They would be even more susceptible to clogging than wide-mesh wedgewire screens (especially in marine environments). It is unclear whether this simply would necessitate more intensive maintenance or preclude their day-to-day use at many sites. Their successful application at Logan and Cope and the historic test data from Florida, Maryland, and Delaware at least suggests promise for addressing both fish impingement and entrainment of eggs and larvae. However, based on the fine-mesh screen experience at Big Bend Units 3 and 4, it is clear that frequent maintenance would be required. Therefore, relatively deep water sufficient to accommodate the large number of screen units, would preferably be close to shore (i.e., be readily accessible). Manual cleaning needs might be reduced or eliminated through use of an automated flushing (e.g., microburst) system.

5.5.3 Fine-Mesh Screens

Technology Overview
Fine-mesh screens are typically mounted on conventional traveling screens and are used to exclude eggs, larvae, and juvenile forms of fish from intakes. These screens rely on gentle impingement of organisms on the screen surface. Successful use of fine-mesh screens is contingent on the application of satisfactory handling and return systems to allow the safe return of impinged organisms to the aquatic environment (Pagano et al, 1977; Sharma, 1978). Fine mesh screens generally include those with mesh sizes of 5 mm or less.

Technology Performance
Similar to fine-mesh wedgewire screens, fine-mesh traveling screens with fish return systems show promise for both I&E control. However, they have not been installed, maintained, and optimized at many facilities. The most significant example of long-term fine-mesh screen use has been at the Big Bend Power Plant in the Tampa Bay area. The facility has an intake canal with 0.5-mm mesh Ristroph screens that are used seasonally on the intakes for Units 3 and 4. During the mid-1980s when the screens were initially installed, their efficiency in reducing I&E mortality was highly variable. The operator, Florida Power & Light (FPL) evaluated different approach velocities and screen rotational speeds. In addition, FPL recognized that frequent maintenance (manual cleaning) was necessary to avoid biofouling. By 1988, system performance had improved greatly. The system's efficiency in screening fish eggs (primarily drums and bay anchovy) exceeded 95 percent with 80 percent latent survival for drum and 93 percent for bay anchovy. For larvae (primarily drums, bay anchovies, blennies, and gobies), screening efficiency was 86 percent with 65 percent latent survival for drum and 66 percent for bay anchovy. (Note that latent survival in control samples was also approximately 60 percent). Although more recent data are generally not available, the screens continue to operate successfully at Big Bend in an estuarine environment with proper maintenance. While egg and larvae entrainment performance are not available, fine mesh (0.5 mm) Passavant screens (single entry/double exit) have been used successfully in a marine environment at the Barney Davis Station in Corpus Christi, Texas. Impingement data for this facility show overall 86 percent initial survivals for bay anchovy, menhaden, Atlantic croaker, killfish, spot, silverside, and shrimp.

Additional full-scale performance data for fine mesh screens at large power stations are generally not available. However, some data are available from limited use/study at several sites and from laboratory and pilot-scale tests. Seasonal use of fine mesh on two of four screens at the Brunswick Power Plant in North Carolina has shown 84 percent reduction in entrainment compared to the conventional screen systems. Similar results were obtained during pilot testing of 1-mm screens at the Chalk Point Generating Station in Maryland, and, at the Kintigh Generating Station in New Jersey, pilot testing indicated 1-mm screens provided 2 to 35 times reductions in entrainment over conventional 9.5-mm screens. Finally, Tennessee Valley Authority (TVA) pilot-scale studies performed in the 1970s showed reductions in striped bass larvae entrainment up to 99 percent using a 0.5-mm screen and 75 and 70 percent for 0.97-mm and 1.3-mm screens, respectively. A full-scale test by TVA at the John Sevier Plant showed less than half as many larvae entrained with a 0.5-mm screen than 1.0 and 2.0-mm screens combined.

Despite the lack of full-scale data, the experiences at Big Bend (as well as Brunswick) show that fine-mesh screens can reduce entrainment by 80 percent or more. This is contingent on optimized operation and intensive maintenance to avoid biofouling and clogging, especially in marine environments. It also may be appropriate to have removable fine mesh that is only used during periods of egg and larval abundance, thereby reduced the potential for clogging and wear and tear on the systems.

5.5.4 Fish Net Barriers

Technology Overview

Fish net barriers are wide-mesh nets, which are placed in front of the entrance to intake structures. The size of the mesh needed is a function of the species that are present at a particular site and vary from 4 mm to 32 mm (EPRI, 2000). The mesh must be sized to prevent fish from passing through the net causing them to become gilled. Relatively low velocities are maintained because the area through which the water can flow is usually large. Fish net barriers have been used at numerous facilities and lend themselves to intakes where the seasonal migration of fish and other organisms require fish diversion facilities for only specific times of the year.

Technology Performance

Barrier nets can provide a high degree of impingement reduction. Because of typically wide openings, they do not reduce entrainment of eggs and larvae. A number of barrier net systems have been used/studied at large power plants. Specific examples include:

- At the J.P. Pulliam Station (Wisconsin), the operator installed 100 and 260-foot barrier nets across the two intake canals, which withdraw water from the Fox River prior to flowing into Lake Michigan. The barrier nets have been shown to reduce impingement by 90 percent over conventional traveling screens without the barrier nets. The facility has the barrier nets in place when the water temperature is greater than 37ºF or April 1 through December 1.

- The Ludington Storage Plant (Michigan) provides water from Lake Michigan to a number of power plant facilities. The plant has a 2.5-mile long barrier net that has successfully reduced I&E. The overall net effectiveness for target species (five salmonids, yellow perch, rainbow smelt, alewife, and chub) has been over 80 percent since 1991 and 96 percent since 1995. The net is deployed from mid-April to mid-October, with storms and icing preventing use during the remainder of the year.

- At the Chalk Point Generating Station (Maryland), a barrier net system has been used since 1981, primarily to reduce crab impingement from the Patuxent River. Eventually, the system was redesigned to include two nets: a 1,200-foot wide outer net prevents debris flows and a 1,000-foot inner net prevents organism flow into the intake. Crab impingement has been reduced by 84 percent. The Agency did not obtain specific fish impingement performance data for other species, but the nets have reduced overall impingement liability for all species from over $2 million to less than $140,000. Net panels are changed twice per week to control biofouling and clogging.

- The Bowline Point Station (New York) has an approximately 150-foot barrier net in a v-shape around the intake structure. Testing during 1976 through 1985 showed that the net effectively reduces white perch and striped bass impingement by 91 percent. Based on tests of a “fine” mesh net (3.0 mm) in 1993 and 1994, researchers found that it could be used to generally prevent entrainment. Unfortunately, species’ abundances were too low to determine the specific biological effectiveness.

- In 1980, a barrier net was installed at the J.R. Whiting Plant (Michigan) to protect Maumee Bay. Prior to net installation, 17,378,518 fish were impinged on conventional traveling screens. With the net, sampling in 1983 and 84 showed 421,978 fish impinged (97 percent effective), sampling in 1987 showed 82,872 fish impinged (99 percent effective), and sampling in 1991 showed 316,575 fish impinged (98 percent effective).

Barrier nets have clearly proven effective for controlling *impingement* (i.e., 80+ percent reductions over conventional screens without nets) in areas with limited debris flows. Experience has shown that high debris flows can cause significant damage to net systems. Biofouling concerns can also be a concern but this can be addressed through frequent maintenance. Barrier nets are also often only used seasonally, where the source waterbody is subject to freezing. Fine-mesh barrier nets show some promise for entrainment control but would likely require even more intensive maintenance. In some cases, the use of barrier nets may be further limited by the physical constraints and other uses of the waterbody.

5.5.5 Aquatic Microfiltration Barriers

Technology Overview
Aquatic microfiltration barrier systems are barriers that employ a filter fabric designed to allow for passage of water into a cooling water intake structure, but exclude aquatic organisms. These systems are designed to be placed some distance from the cooling water intake structure within the source waterbody and act as a filter for the water that enters into the cooling water system. These systems may be floating, flexible, or fixed. Since these systems generally have such a large surface area, the velocities that are maintained at the face of the permeable curtain are very low. One company, Gunderboom, Inc., has a patented full-water-depth filter curtain comprised of polyethylene or polypropylene fabric that is suspended by flotation billets at the surface of the water and anchored to the substrate below. The curtain fabric is manufactured as a matting of minute unwoven fibers with an apparent opening size of 20 microns. Gunderboom systems also employ an automated “air burst” system to periodically shake the material and pass air bubbles through the curtain system to clean it of sediment buildup and release any other material back into the water column.

Technology Performance
The Agency has determined that microfiltration barriers, including the Gunderboom, show significant *promise* for minimizing entrainment. However, the Agency acknowledges that Gunderboom technology is currently “experimental in nature.” At this juncture, the only power plant where the Gunderboom has been used at a “full-scale” level is the Lovett Generating Station along the Hudson River in New York, where pilot testing began in the mid-1990s. Initial testing at this facility showed significant potential for reducing entrainment. Entrainment reductions up to 82 percent were observed for eggs and larvae and these levels have been maintained for extended month-to-month periods during 1999 through 2001. At Lovett, there have been some operational difficulties that have affected long-term performance. These difficulties, including tearing, overtopping, and plugging/clogging, have been addressed, to a large extent, through subsequent design modifications. Gunderboom, Inc. specifically has designed and installed a “microburst” cleaning system to remove particulates. Each of the challenges encountered

at Lovett could be significantly greater concern at marine sites with higher wave action and debris flows. Gunderboom systems have been otherwise deployed in marine conditions to prevent migration of particulates and bacteria. They have been used successfully in areas with waves up to five feet. The Gunderboom system is currently being tested for potential use at the Contra Costa Plant along the San Joaquin River in Northern California.

An additional question related to the utility of the Gunderboom and other microfiltration systems is sizing and the physical limitations and other uses of the source waterbody. With a 20-micron mesh, 100,000 and 200,000 gallon per minute intakes would require filter systems 500 and 1,000 feet long (assuming 20 foot depth). In some locations, this may preclude its successful deployment due space limitations and/or conflicts with other waterbody uses.

5.5.6 Louver Systems

Technology Overview
Louver systems consist of series of vertical panels placed at 90 degree angles to the direction of water flow (Hadderingh, 1979). The placement of the louver panels provides both changes in the flow direction and velocity, which fish tend to avoid. The angles and flow velocities of the louvers create a current parallel to the face of the louvers which carries fish away from the intake and into a fish bypass system for return to the source waterbody.

Technology Performance
Louver systems can reduce impingement losses based on fishes' abilities to recognize and swim away from the barriers. Their performance, i.e., guidance efficiency, is highly dependant on the length and swimming abilities of the resident species. Since eggs and early stages of larvae cannot "swim away," they are not affected by the diversions and there is no associated reduction in entrainment.

While louver systems have been tested at a number of laboratory and pilot-scale facilities, they have not been used at many full-scale facilities. The only large power plant facility where a louver system has been used is San Onofre Units 2 and 3 (2,200 MW combined) in Southern California. The operator initially tested both louver and wide mesh, angled traveling screens during the 1970s. Louvers were subsequently selected for full-scale use at the intakes for the two units. In 1984, a total of 196,978 fish entered the louver system with 188,583 returned to the waterbody and 8,395 impinged. In 1985, 407,755 entered the louver system with 306,200 returned and 101,555 impinged. Therefore, the guidance efficiencies in 1984 and 1985 were 96 and 75 percent, respectively. However, 96-hour survival rates for some species, i.e., anchovies and croakers, were 50 percent or less. The facility also has encountered some difficulties with predator species congregating in the vicinity of the outlet from the fish return system. Louvers were originally considered for use at San Onofre because of 1970s pilot testing at the Redondo Beach Station in California where maximum guidance efficiencies of 96-100 percent were observed.

EPRI 2000 indicated that louver systems could provide 80-95 percent diversion efficiency for a wide variety of species under a range of site conditions. This is generally consistent with the American Society of Civil Engineers' (ASCE) findings from the late 1970s which showed almost all systems had diversion efficiencies exceeding 60 percent with many more than 90 percent. As indicated above, much of the EPRI and ASCE data come from pilot/laboratory tests and hydroelectric facilities where louver use has been more widespread than at steam electric facilities. Louvers were specifically tested by the Northeast Utilities Service Company in the Holyoke Canal on the Connecticut River for juvenile clupeids (American shad and blueback herring). Overall guidance efficiency was found to be 75-90 percent. In the 1970s, Alden Research Laboratory observed similar results for Hudson River species (including alewife and smelt). At the Tracy Fish Collection Facility located along the San Joaquin River in California, testing was performed from 1993 and 1995 to determine the guidance efficiency of a system with primary and secondary louvers. The results for green and white sturgeon, American shad, splittail, white catfish, delta smelt, Chinook salmon, and striped bass showed mean diversion efficiencies ranging from 63 (splittail) to 89 percent (white catfish). Also in the 1990s, an experimental louver bypass system was tested at the USGS' Conte Anadromous Fish Research Center in Massachusetts. This testing showed guidance efficiencies for Connecticut River species of 97 percent for a "wide array" of louvers and 100 percent for a "narrow array." Finally, at the T.W. Sullivan Hydroelectric Plant along the Williamette River in Oregon, the louver system is estimated to be 92 percent effective in diverting spring Chinook, 82 percent for all Chinook, and 85 percent for steelhead. The system has been optimized to reduce fish injuries such that the average injury occurrence is only 0.44 percent.

Overall, the above data indicate that louvers can be highly effective (70+ percent) in diverting fish from potential impingement. Latent mortality is a concern, especially where fragile species are present. Similar to modified screens with fish return systems, operators must optimize louver system design to minimize fish injury and mortality

5.5.7 Angled and Modular Inclined Screens

Technology Overview

Angled traveling screens use standard through-flow traveling screens where the screens are set at an angle to the incoming flow. Angling the screens improves the fish protection effectiveness since the fish tend to avoid the screen face and move toward the end of the screen line, assisted by a component of the inflow velocity. A fish bypass facility with independently induced flow must be provided (Richards 1977). Modular inclined screens (MISs) are a specific variation on angled traveling screens, where each module in the intake consists of trash racks, dewatering stop logs, an inclined screen set at a 10 to 20 degree angle to the flow, and a fish bypass (EPRI 1999).

Technology Performance

Angled traveling screens with fish bypass and return systems work similarly to louver systems. They also only provide potential reductions in impingement mortality since eggs and larvae will not generally detect the factors that influence diversion. Similar to louver systems, they were tested extensively at the laboratory and pilot scales, especially during the 1970s and early 1980s. Testing of angled screens (45 degrees to the flow) in the 1970s at San Onofre showed poor to good guidance (0-70 percent) for northern anchovies with moderate to good guidance (60-90 percent) for other species. Latent survival varied by species with fragile species only having 25 percent survival, while hardy species showed greater than 65 percent survival. The intake for Unit 6 at the Oswego Steam plant along Lake Ontario in New York has traveling screens angled to 25 degrees. Testing during 1981 through 1984 showed a combined diversion efficiency of 78 percent for all species; ranging from 53 percent for mottled sculpin to 95 percent for gizzard shad. Latent survival testing results ranged from 22 percent for alewife to nearly 94 percent for mottled sculpin.

Additional testing of angled traveling screens was performed in the late 1970s and early 1980s for power plants on Lake Ontario and along the Hudson River. This testing showed that a screen angled at 25 degrees was 100 percent effective in diverting 1 to 6 inch long Lake Ontario fish. Similar results were observed for Hudson River species (striped bass, white perch, and Atlantic tomcod). One-week mortality tests for these species showed 96 percent survival. Angled traveling screens with a fish return system have been used on the intake from Brayton Point Unit 4. Studies from 1984 through 1986 that evaluated the angled screens showed a diversion efficiency of 76 percent with latent survival of 63 percent. Much higher results were observed excluding bay anchovy. Finally, 1981 full-scale studies of an angled screen system at the Danskammer Station along the Hudson River in New York showed diversion efficiencies of 95 to 100 percent with a mean of 99 percent. Diversion efficiency combined with latent survival yielded a total effectiveness of 84 percent. Species included bay anchovy, blueback herring, white perch, spottail shiner, alewife, Atlantic tomcod, pumpkinseed, and American shad.

During the late 1970s and early 1980s, Alden Research Laboratories (Alden) conducted a range of tests on a variety of angled screen designs. Alden specifically performed screen diversion tests for three northeastern utilities. In initial studies for Niagara Mohawk, diversion efficiencies were found to be nearly 100 percent for alewife and smolt. Follow-up tests for Niagara Mohawk confirmed 100 percent diversion efficiency for alewife with mortalities only four percent higher than control samples. Subsequent tests by Alden for Consolidated Edison, Inc. using striped bass, white perch, and tomcod also found nearly 100 percent diversion efficiency with a 25 degree angled screen. The one-week mean mortality was only 3 percent.

Alden further performed tests during 1978-1990 to determine the effectiveness of fine-mesh, angled screens. In 1978, tests were performed with striped bass larvae using both 1.5 and 2.5-mm mesh and different screen materials and approach velocity. Diversion efficiency was found to clearly be a function of larvae length. Synthetic materials were also found to be more effective than metal screens. Subsequent testing using only synthetic materials found that 1.0 mm screens can provide post larvae diversion efficiencies of greater than 80 percent. However, the tests found that latent mortality for diverted species was also high.

Finally, EPRI tested modular inclined screens (MIS) in a laboratory in the early 1990s. Most fish had diversion efficiencies of 47 to 88 percent. Diversion efficiencies of greater than 98 percent were observed for channel catfish, golden shiner, brown trout, Coho and Chinook salmon, trout fry and juveniles, and Atlantic salmon smolts. Lower diversion efficiency and higher mortality were found for American shad and blueback herring but comparable to control mortalities. Based on the laboratory data, a MIS system was pilot-tested at a Niagara Mohawk hydroelectric facility on the Hudson River. This testing showed diversion efficiencies and survival rates approaching 100 percent for golden shiners and rainbow trout. High diversion and survival was also observed for largemouth and smallmouth bass, yellow perch, and bluegill. Lower diversion efficiency and survival was found for herring.

Similar to louvers, angled screens show potential to minimize impingement by greater than 80 to 90 percent. More widespread full-scale use is necessary to determine optimal design specifications and verify that they can be used on a widespread basis.

5.5.8 Velocity Caps

Technology Description

A velocity cap is a device that is placed over vertical inlets at offshore intakes. This cover converts vertical flow into horizontal flow at the entrance into the intake. The device works on the premise that fish will avoid rapid changes in horizontal flow. In general, velocity caps have been installed at many offshore intakes and have been successful in minimizing impingement.

Technology Performance

Velocity caps can reduce fish drawn into intakes based on the concept that they tend to avoid horizontal flow. They do not provide reductions in entrainment of eggs and larvae, which cannot distinguish flow characteristics. As noted in *ASCE 1981*, velocity caps are often used in conjunction with other fish protection devices. Therefore, there are somewhat limited data on their performance when used alone. Facilities that have velocity caps include:

- Oswego Steam Units 5 and 6 in New York (combined with angled screens on Unit 6).
- San Onofre Units 2 and 3 in California (combined with louver system).
- El Segundo Station in California
- Huntington Beach Station in California
- Edgewater Power Plant Unit 5 in Wisconsin (combined with 9.5 mm wedgewire screen)

- Nanticoke Power Plant in Ontario, Canada
- Nine Mile Point in New York
- Redondo Beach Station in California
- Kintigh Generation Station in New York (combined with modified traveling screens)
- Seabrook Power Plant in New Hampshire
- St. Lucie Power Plant in Florida.

At the Huntington Beach and Segundo Stations in California, velocity caps have been found to provide 80 to 90 percent reductions in fish entrapment. At Seabrook, the velocity cap on the offshore intake has minimized the number of pelagic fish entrained except for pollock. Finally, two facilities in England have velocity caps on one of each's two intakes. At the Sizewell Power Station, intake B has a velocity cap, which reduces impingement about 50 percent compared to intake A. Similarly, at the Dungeness Power Station, intake B has a velocity cap, which reduces impingement about 62 percent compared to intake A.

5.5.9 Porous Dikes and Leaky Dams

Technology Overview
Porous dikes, also known as leaky dams or dikes, are filters resembling a breakwater surrounding a cooling water intake. The core of the dike consists of cobble or gravel that permits free passage of water. The dike acts both as a physical and behavioral barrier to aquatic organisms. Tests conducted to date have indicated that the technology is effective in excluding juvenile and adult fish. The major problems associated with porous dikes come from clogging by debris and silt, ice build-up, and by colonization of fish and plant life.

Technology Performance
Porous dike technologies work on the premise that aquatic organisms will not pass through physical barriers in front of an intake. They also operate with low approach velocity further increasing the potential for avoidance. However, they will not prevent entrainment by non-motile larvae and eggs. Much of the research on porous dikes and leaky dams was performed in the 1970s. This work was generally performed in a laboratory or on a pilot level, i.e., the Agency is not aware of any full-scale porous dike or leaky dam systems currently used at power plants in the U.S. Examples of early study results include:

- Studies of porous dike and leaky dam systems by Wisconsin Electric Power at Lake Michigan plants showed generally lower I&E rates than other nearby onshore intakes.

- Laboratory work by Ketschke showed that porous dikes could be a physical barrier to juvenile and adult fish and a physical or behavioral barrier to some larvae. All larvae except winter flounder showed some avoidance of the rock dike.

- Testing at the Brayton Point Power Plant showed that densities of bay anchovy larvae downstream of the dam were reduced by 94 to 99 percent. For winter flounder, downstream densities were lower by 23 to 87 percent. Entrainment avoidance for juvenile and adult finfish was observed to be nearly 100 percent.

As indicated in the above examples, porous dikes and leaky dams show *potential* for use in limiting passage of adult and juvenile fish, and, to some degree, motile larvae. However, the lack of more recent, full-scale performance data makes it difficult to predict their widespread applicability and specific levels of performance.

5.5.10 Behavioral Systems

Technology Overview
Behavioral devices are designed to enhance fish avoidance of intake structures and/or promote attraction to fish diversion or bypass systems. Specific technologies that have been considered include:

- Light Barriers: Light barriers consist of controlled application of strobe lights or mercury vapor lights to lure fish away from the cooling water intake structure or deflect natural migration patterns. This technology is based on research that shows that some fish avoid light, however it is also known that some species are attracted by light.

- Sound Barriers: Sound barriers are non-contact barriers that rely on mechanical or electronic equipment that generates various sound patterns to elicit avoidance responses in fish. Acoustic barriers are used to deter fish from entering cooling water intake structures. The most widely used acoustical barrier is a pneumatic air gun or "popper."

- Air bubble barriers: Air bubble barriers consist of an air header with jets arranged to provide a continuous curtain of air bubbles over a cross section area. The general purpose of air bubble barriers is to repel fish that may attempt to approach the face of a CWIS.

Technology Performance
Many studies have been conducted and reports prepared on the application of behavioral devices to control I&E, see EPRI 2000. For the most part, these studies have either been inconclusive or shown no tangible reduction in impingement or entrainment. As a result, the full-scale application of behavioral devices has been limited. Where data are available, performance appears to be highly dependent on the types and sizes of species and environmental conditions. One exception may be the use of sound systems to divert alewife. In tests at the Pickering Station in Ontario, poppers were found to be effective in reducing alewife I&E by 73 percent in 1985 and 76 percent in 1986. No benefits were observed for rainbow smelt and gizzard shad. 1993 testing of sound systems at the James A. Fitzpatrick Station in New York showed similar results, i.e., 85 percent reductions in alewife I&E through use of a high frequency sound system. At the Arthur Kill Station, pilot- and full-scale, high frequency sound tests showed comparable results for alewife to Fitzpatrick and Pickering. Impingement of gizzard shad was also three times less than without the system. No deterrence was observed for American shad or bay anchovy using the full-scale system. In contrast, sound provided little or no deterrence for any species at the Roseton Station in New York. Overall, the Agency expects that behavioral systems would be used in conjunction with other technologies to reduce I&E and perhaps targeted towards an individual species (e.g., alewife).

5.5.11 Other Technology Alternatives

The proposed new facility rule does not specify the individual technology (or group of technologies) to be used to minimize I&E to same levels as those achieved with the Track I requirements based, in part, on wet, closed-cycle cooling system. In addition to the above technologies, there are other approaches that may be used on a site-by-site basis. For example:

- Use of variable speed pumps can provide for greater system efficiency and reduced flow requirements (and associated entrainment) by 10-30 percent. EPA Region 4 estimated that use of variable speed pumps at the Canaveral and Indian River Stations in the Indian River estuary would reduce entrainment by 20 percent. Presumably, such pumps would have to be used in conjunction with other technologies. EPA conservatively estimated that facilities complying with the requirements final rule would install variable speed pumps regardless of the baseline cooling system projected for the facility. See Chapter 2 of this document for more information.

- Perforated pipes draw water through perforations or elongated slots in a cylindrical section placed in the waterway. Early designs of this technology were not efficient, velocity distribution was poor, and they were specifically designed to screen out detritus (i.e., not used for fish protection) (ASCE, 1982). Inner sleeves were subsequently added to perforated pipes to equalize the velocities entering the outer perforations. These systems have historically been used at locations requiring small amounts of make-up water. Experience at steam electric plants is very limited (Sharma, 1978). Perforated pipes are used on the intakes for the Amos and Mountaineer Stations along the Ohio River. However, I&E performance data for these facilities are unavailable. In general, EPA projects that perforated pipe system performance should be comparable to wide-mesh wedgewire screens (e.g., at Eddystone Units 1 and 2 and Campbell Unit 3).

- At the Pittsburg Plant in California, impingement survival was studied for continuously rotated screens versus intermittent rotation. Ninety-six-hour survival for young-of-year white perch was 19 to 32 percent for intermittent screen rotation versus 26 to 56 percent for continuous rotation. Striped bass latent survival increased from 26 to 62 percent when continuous rotation was used. Similar studies were also performed at Moss Landing Units 6 and 7, where no increased survival was observed for hardy and very fragile species, however, there was a substantial increase in impingement survival for surfperch and rockfish.

- Facilities may be able to use recycled cooling water to reduce intake flow needs. The Brayton Point Station has a “piggyback” system where the entire intake requirements for Unit 4 can be met by recycled cooling water from Units 1 through 3. The system has been used sporadically since 1993 and reduces the make-up water needs (and thereby entrainment) by 29 percent.

5.6 Intake Location

Beyond design alternatives for CWISs, an operator may able to locate CWISs offshore or otherwise in areas that minimize I&E (compared to conventional onshore locations). It is well known that there are certain areas within every waterbody with increased biological productivity, and therefore where the potential for I&E of organisms is higher.

In large lakes and reservoirs, the littoral zone (i.e., shorezone areas where light penetrates to the bottom) of lakes/reservoirs serves as the principal spawning and nursery area for most species of freshwater fish and is considered one of the most productive areas of the waterbody. Fish of this zone typically follow a spawning strategy wherein eggs are deposited in prepared nests, on the bottom, and/or are attached to submerged substrates where they incubate and hatch. As the larvae mature, some species disperse to the open water regions, whereas many others complete their life cycle in the littoral zone. Clearly, the impact potential for intakes located in the littoral zone of lakes and reservoirs is high. The profundal zone of lakes/reservoirs is the deeper, colder area of the waterbody. Rooted plants are absent because of insufficient light, and for the same reason, primary productivity is minimal. A well-oxygenated profundal zone can support benthic macroinvertebrates and cold-water fish; however, most of the fish species seek shallower areas to spawn (either in littoral areas or in adjacent streams/rivers). Use of the deepest open water region of a lake and reservoir (e.g., within the profundal zone) as a source of cooling water typically offers lower I&E impact potential (than use of littoral zone waters).

As with lakes/reservoirs, rivers are managed for numerous benefits, which include sustainable and robust fisheries.

Unlike lakes and reservoirs, the hydrodynamics of rivers typically result in a mixed water column and (overall) unidirectional flow. There are many similarities in the reproductive strategies of shoreline fish populations in rivers and the reproductive strategies of fish within the littoral zone of lakes/reservoirs. Planktonic movement of eggs, larvae, post larvae, and early juvenile organisms along the shorezone are generally limited to relatively short distances. As a result, the shorezone placement of CWISs in rivers may potentially impact local spawning populations of fish. The impact potential associated with entrainment may be diminished if the main source of cooling water is recruited from near the bottom strata of the open water channel region of the river. With such an intake configuration, entrainment of shorezone eggs and larvae, as well as the near surface drift community of ichthyoplankton, is minimized. Impacts could also be minimized by the control of the timing and frequency of withdrawals from rivers. In temperate regions, the number of entrainable/impingeable organisms of rivers increases during spring and summer (when many riverine fishes reproduce). The number of eggs and larvae peak at that time, whereas entrainment potential during the remainder of the year may be minimal.

In estuaries, species distribution and abundance are determined by a number of physical and chemical attributes including: geographic location, estuary origin (or type), salinity, temperature, oxygen, circulation (currents), and substrate. These factors, in conjunction with the degree of vertical and horizontal stratification (mixing) in the estuary, help dictate the spatial distribution and movement of estuarine organisms. However, with local knowledge of these characteristics, the entrainment effects of a CWIS could be minimized by adjusting the intake design to areas (e.g., depths) least likely to impact upon concentrated numbers and species of organisms.

In oceans, nearshore coastal waters are generally the most biologically productive areas. The euphotic zone (zone of photosynthetic available light) typically does not extend beyond the first 100 meters (328 feet) of depth. Therefore, inshore waters are generally more productive due to photosynthetic activity, and due to the input from estuaries and runoff of nutrients from land.

There are limited published data *quantifying* the locational differences in I&E rates at individual power plants. However, some information is available for selected sites. For example,

- For the St. Lucie plant in Florida, EPA Region 4 permitted the use of a once through cooling system instead of closed-cycle cooling by locating the outfall 1,200 offshore (with a velocity cap) in the Atlantic Ocean. This avoided impacts on the biologically sensitive Indian River estuary.

- In *Entrainment of Fish Larvae and Eggs on the Great Lakes, with Special Reference to the D.C. Cook Nuclear Plant, Southeastern Lake Michigan* (1976), researchers noted that larval abundance is greatest within about the 12.2-m (40 ft) contour to shore in Lake Michigan and that the abundance of larvae tends to decrease as one proceeds deeper and farther offshore. This led to the suggestion of locating CWISs in deep waters.

- During biological studies near the Fort Calhoun Power Station along the Missouri River, results of transect studies indicated significantly higher fish larvae densities along the cutting bank of the river, adjacent to the Station's intake structure. Densities were generally were lowest in the middle of the channel.

5.7 SUMMARY

Tables 5-1 and 5-2 summarize I&E performance data for selected, existing facilities. The Agency recognizes that these data are somewhat variable, in part depending on site-specific conditions. This is also because there generally have not been uniform performance standards for specific technologies. However, during the past 30 years, significant experience has been gained in optimizing the design and maintenance of CWIS technologies under various site and environmental conditions. Through this experience and the performance requirements under Track II of the proposed new facility rule, the Agency is confident that technology applicability and performance will continue to be improved

The Agency has concluded that the data indicate that several technologies, i.e., wide-mesh wedgewire screens and barrier systems, will generally minimize impingement to levels comparable to wet, closed cycle cooling systems. Other technologies, such as modified traveling screens with fish handling and return systems, and fish diversion systems, are likely to be viable at some sites (especially those with hardy species present). In addition, these technologies may be used in groups, e.g., barrier nets and modified screens, depending on site-specific conditions.

Demonstrating that alternative design technologies can achieve comparable entrainment performance to closed-cycle systems is more problematic largely because there are relatively few fully successful examples of full-scale systems being deployed and tested. However, the Agency has determined that fine-mesh traveling screens with fish return systems, fine-mesh wedgewire screens and microfiltration barriers (e.g., gunderbooms) are all promising technologies that could provide a level of protection reasonably consistent with the I&E protection afforded by wet, closed-cycle cooling. In addition, the Agency is also confident that on a site-by-site basis, many facilities will be able to further minimize entrainment (and impingement) by optimizing the location and timing of cooling water withdrawals. Similarly, habitat restoration could also be used, as appropriate as needed, in conjunction with CWIS technologies and/or locational requirements.

Table 5-1: Impingement Performance

Site	Location	Name/Type of Waterbody	Technology	Impingement	Entrainment	Notes
Diablo Canyon/Moss Landing	California	Pacific Ocean	Modified traveling/fish return	75	0	
Brayton Point	Massachusetts	Mt. Hope Bay (Estuary)	Angled screens/fish return	76	0	63% latent
Danskammer	New York	Tidal River (Hudson)	Angled screens/fish return	99	0	84% latent
Monroe	Michigan	River/Great Lake	Fish pump/return (screenwell)	70-80	0	Raisin River trib to L. Erie
Holyoke Canal	Connecticut	Connecticut River Basin	Louvers	85-90	0	Test results
Tracy Fish Collection	California	San Joaquin River	Louvers	63-89	0	
Salem	New Jersey	Tidal River (Delaware)	Ristroph screens	18-98	0	Species specific (no avg.)
Redondo Beach	California	Pacific Ocean	Louvers	96-100	0	Test for San Onofre
San Onofre	California	Pacific Ocean	Louvers	75-96	0	
Dominion Power Surry	Virginia	Estuary (James River)	Modified Fish/fish return	94	0	Includes survival
Barney Davis	Texas	Estuary (coastal lagoon)	Passavant screens (1.5 mm)	86	NA	Entrainment data Not Avail
Kintigh	New York	Great Lake	Modified with fish return	>80	50-97	Except shad 54-65, alewife 15-44
Calvert Cliffs	Maryland	Bay/estuary	Dual flow, cont. rot., return	73	0	Includes survival
Arthur Kill	New York	Estuary	Ristroph screens	79-92	0	
J.H. Campbell	Michigan	Great Lake	Wide mesh wedgewire	99+	0	
Eddystone	Pennsylvania	Estuary (Delaware)	Wide mesh wedgewire	99+	0	
Lovett	New York	Tidal River (Hudson)	Gunderboom	99	82	
J.P. Pulliam	Wisconsin	River/Great Lake	Barrier net	90	0	Only when above 37 degrees C
Ludington Storage	Michigan	Great Lake	Barrier net	96	0	
Chalk Point	Maryland	Bay/Estuary	Barrier net	90+	0	Based on liability reduced 93%
Bowline	New York	Tidal River (Hudson)	Barrier net	91	0	
J.R. Whiting	New York	Great Lake	Barrier net	97-99	0	
D.C. Cook	Michigan	Great Lake	Barrier net	80	0	Estimated by U. of Michigan
Oswego Steam	New York	Great Lake	Velocity cap	78	0	

Table 5-2: Entrainment Performance

Site	Location	Name/Type of Waterbody	Technology	Impingement	Entrainment	Notes
Big Bend	Florida	Tampa Bay	Fine mesh traveling	NA	86-95	66-93% survival
Seminole	Florida	River/Estuary	Fine mesh wedgewire	NA	99	Testing, not full-scale
Logan	New Jersey	River/Estuary	Fine mesh wedgewire	NA	90	19 mgd
TVA (studies)	Various	Fresh Water	Fine mesh traveling	NA	99	lab testing, striped bass larvae only
Lovett	New York	River/Tidal	Gunderboom	99	82	
Brunswick	North Carolina	River/Estuary	Fine mesh traveling	NA	84	used only when less than 84 deg F
Chalk Point	Maryland	Bay/Estuary	Fine mesh wedgewire	NA	80	Testing, not full-scale
Kintigh	New York	Great Lake	Fine mesh traveling	>80	50-97	
Summit	Delaware	Bay/Estuary	Fine mesh wedgewire	NA	90+	"impingement eliminated"

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